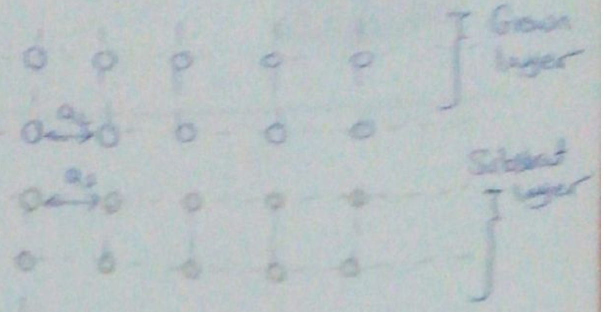
Sec (7)

1. ~~Rembers~~ Remember: lattice matched Hetero structure used for Radiative transitions

lattice Matched Hetero structure ⇒

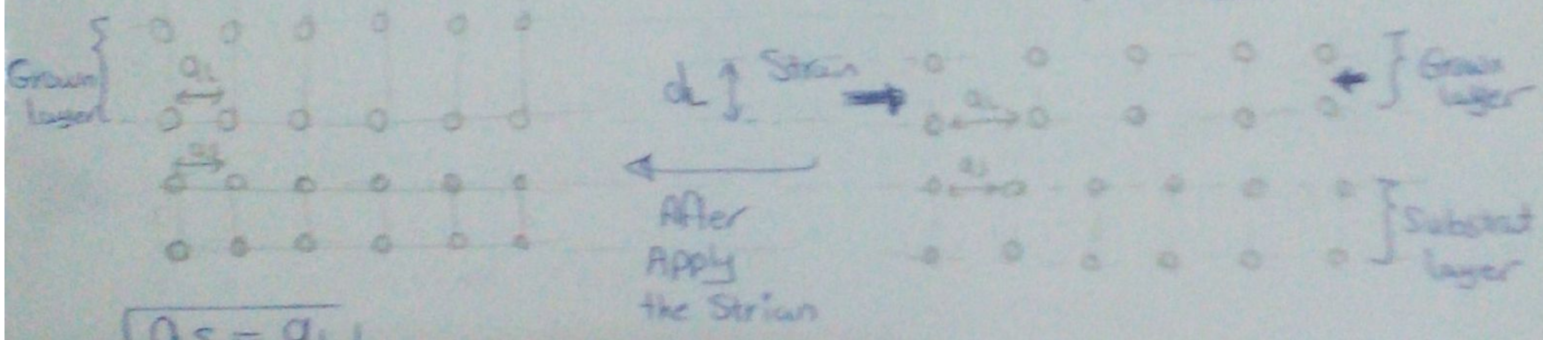


[Because $a_s = a_L$]

2. **Strained layer epitaxy**

↳ if $a_s \neq a_L$ → [lattice mismatch]

↳ To fix this problem
* Apply strain to the Grown layer from sides



لاحظ ان طول الـ Grown layer زاد
" كأنك لما ضغط جزء زاد من الجزء التاني ← زي العجان "

ماهو الشرط الواجب توافره حتى يمكن استخدام الـ Strain لحل مشكلة الـ mismatch

↳ Condition to use strained layers:

$$d_L < d_{critical}$$

Where: $d_c = \dfrac{a_s}{2|\varepsilon|}$

& $\boxed{\varepsilon = \dfrac{a_L - a_s}{a_L}}$

$\varepsilon \rightarrow$ mismatch parameter $\rightarrow$ if $\varepsilon = 0 \Rightarrow a_s = a_L$ Matched

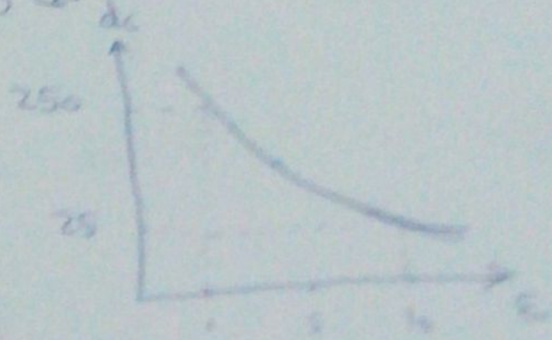
$\varepsilon \neq 0 \rightarrow a_s \neq a_L$ ↳ Mismatched

<u>Ex:</u> For Semiconductor $a_s = 5 A^\circ$ if $\varepsilon = 1\% \rightarrow 10\%$ ($1\% \to 0.01$, $10\% \to 0.1$)

at $\varepsilon = 0.01 \rightarrow d_c = \dfrac{5 A^\circ}{2 * 0.01} = 250 A^\circ$

$\varepsilon = 0.1 \rightarrow d_c = \dfrac{5}{2 * 0.1} = \underline{25 A^\circ}$

كل ما زاد الـ Mismatch " ε " ← قل الـ d_c



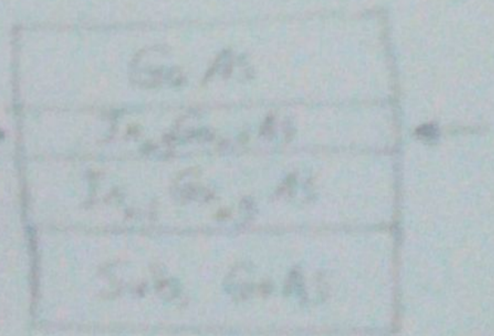
<u>Ex:</u> To build optical Source from $In_x Ga_{1-x} As / GaAs$

at $x = 0 \rightarrow GaAs \rightarrow a = 5.65 A^\circ$

$x = 1 \rightarrow InAs \rightarrow a = 5.87 A^\circ$

↳ ~~mismo~~ lattice mismatch Can be modified by Compressive strain only when $\boxed{d_L < d_c}$

$d_L \updownarrow$ Compressive strain $\rightarrow$



في سكشن (5) أو سؤال ← اقترح تصميم لـ optical source
ممكن تستخدم التصميم اللي فوق وتكتب الشرط

1. Interaction of light with matter.

↳ What is debroglie Wavelength?

$$\boxed{\lambda = \frac{2\pi}{K} = \frac{2\pi\hbar}{P} = \frac{h}{\sqrt{2m^*E}}}$$

Ex: Compute λ debroglie wavelength at $T = 300\,°K$ & $m_c^* = 0.067 m_o$

$$E_{KE} = \frac{1}{2} m^* v^2 = \frac{P^2}{2m^*}$$

$\therefore P = \sqrt{2 m^* E}$ ← effective mass

$$\therefore \lambda = \frac{h}{\sqrt{2 m_c^* E_{KE}}}$$

$$E_{K.E} = KT = 0.025\ eV$$

$$\lambda = \frac{h}{\sqrt{2 * 0.067 * m_o * 0.025 * e}} = 300\ A°$$

ثوابت في ال Calculator

So

↳ if we use d_L (in Double Heterostructure) = 100 A°

↳ This structure will be Quantum well structure.

↳ What will happen to Allowed States in Active layer if its thickness decrease?

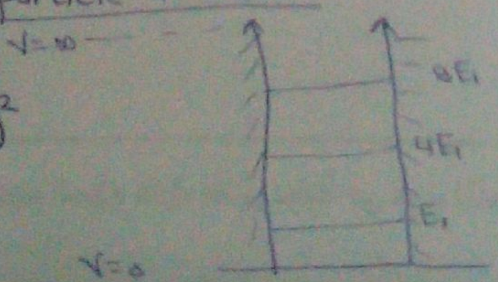
Remember particle in the Box

[illegible]

$$E = \frac{\hbar^2}{2m}\left(\frac{n\pi}{L}\right)^2$$

$$E_1 = \frac{\hbar^2}{2m}\left(\frac{\pi}{L}\right)^2$$

$$E_2 = 4E_1$$

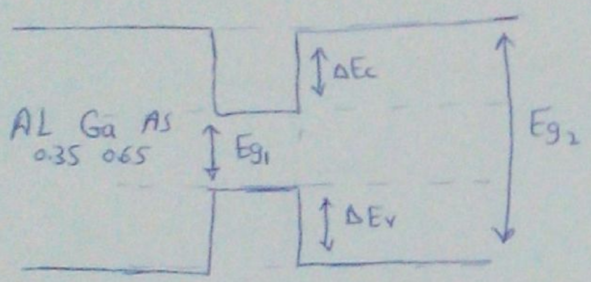


↳ Interaction of light with matter:

Ex: Find Emission wavelength can be controlled by change the thickness of the active layer?

For $Al_{0.35}Ga_{0.65}As / GaAs / Al_{0.35}Ga_{0.65}As$

~Sol~



For $Al_{0.35}Ga_{0.65}As$

$E_{g_2} = 1.424 + 1.242\,X$

$\boxed{E_{g_2} = 1.86}$ ev

For GaAs

$\boxed{E_{g_1} = 1.42 \text{ ev}}$

Note for most optoelectronic material ~~optical communication~~

$\Delta E_c = 0.65\,\Delta E_g$

$\Delta E_v = 0.35\,\Delta E_g$

$\therefore \boxed{\Delta E_g = 1.86 - 1.42 = 0.44 \text{ ev}}$

$\therefore \Delta E_c \simeq 0.29$ ev

$\Delta E_v \simeq 0.15$ ev

Range for emission wavelength:

From $E_{g_2} = 1.86$ ev $\rightarrow \lambda_2 = 0.67\ \mu m$

$E_{g_1} = 1.42$ ev $\rightarrow \lambda_1 = 0.87\ \mu m$

$\boxed{\lambda \rightarrow 0.67\ \mu m \rightarrow 0.87\ \mu m}$

Q (4) ⓐ

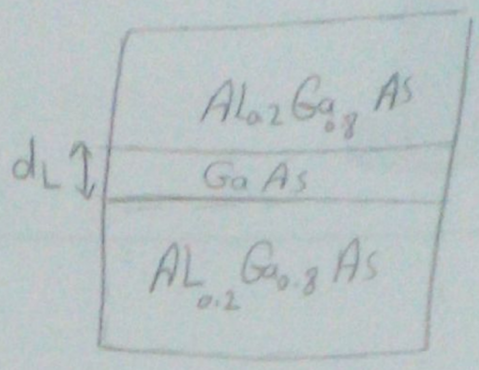
Same Example in page ⑥

↳ Quantum Well Structure

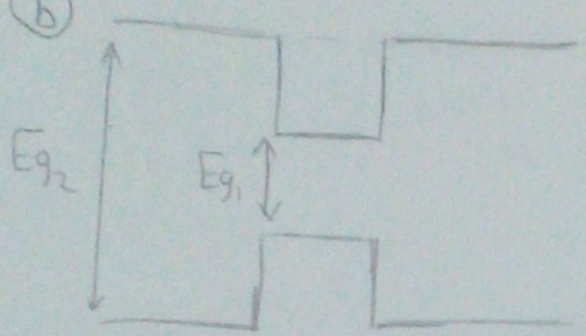
$d_L < \lambda_e$

$\boxed{\lambda_e = 300\,\mathring{A}}$

debroglie wavelength



ⓑ



$Eg_1 \big|_{GaAs} = 1.42$

$Eg_2 \big|_{Al_{0.2}Ga_{0.8}As} = 1.424 + 1.23(0.2)$

$\boxed{Eg_2 = 1.67}$

ⓒ

Application

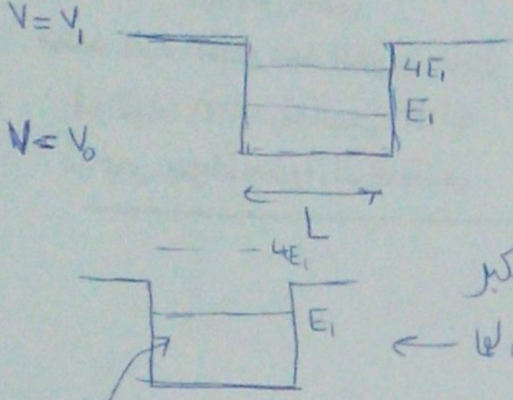
↳ laser Source (To explain the operation see page 15)

ⓓ Max and Min wavelength :

$Eg_2 \big|_{max} = 1.67\,ev \rightarrow \lambda_2 \big|_{min} = \frac{1.24}{1.67} = 0.74\,\mu m$

$Eg_1 \big|_{min} = 1.42\,ev \rightarrow \lambda_1' \big|_{max} = \frac{1.24}{1.42} = 0.87\,\mu m$

~~the~~ But in finite Quantum well



if L ⇝ decrease

$\therefore E_1\uparrow = \frac{\hbar^2}{2m}\left(\frac{\pi}{L}\right)^2$

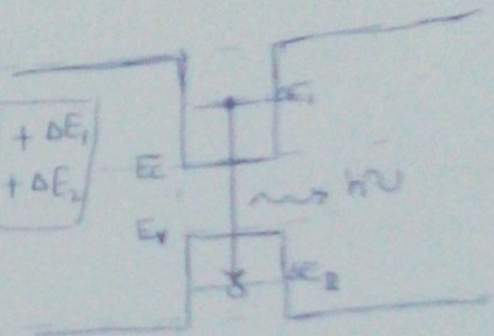
قيمة E_1 هتكبر

يعني هيحصلها shift لأ اعلى

يبقى عن طريق التحكم في ال thickness بحيث يبقى اقل من λ_{de}

هقدر احصل على one allowed state

$$\boxed{Eg_{effective} = (E_c - E_v) + \Delta E_1 + \Delta E_2}$$



من ال Quantum well structure ممكن احصل على photon with single freq. ⇐ $\boxed{\text{laser Source}}$

$\boxed{\text{Quantum well structure used in Laser Source}}$

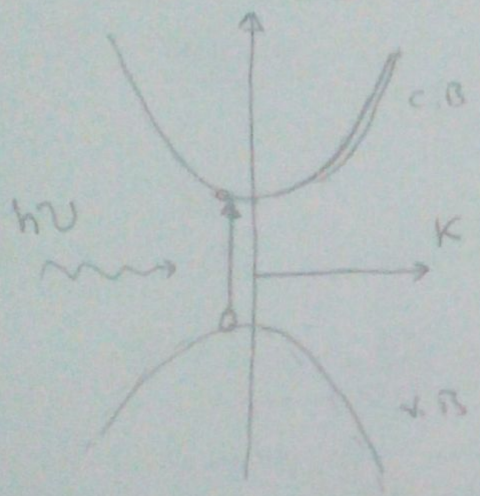
$Eg_{effective} = (E_c - E_v) + \Delta E_1 + \Delta E_2$

↳ Band Gap Controlled by Sandwished layer

Interaction of light with matter:

- Absorption
- Emission
  - Sponteneous emission
  - Stimulated emission

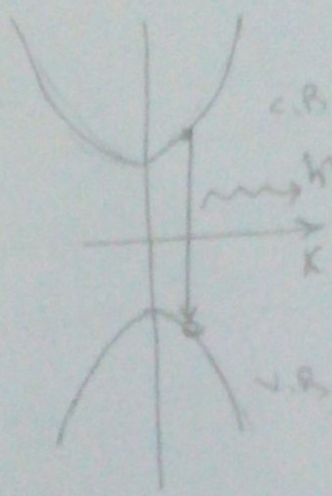
1] Absorption



↳ Input photon create hole_electron pair.

application → $\boxed{\text{photodetector}}$

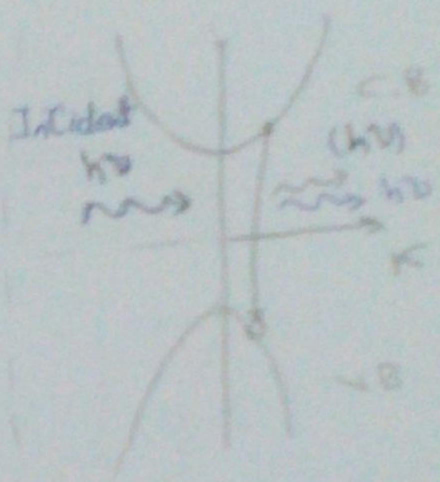
2] Sponteneous



↳ Transition of electron from c.B → v.B create photon

Application $\boxed{\text{LED}}$

3] Stimulated



Incident photon in phase with the resulted photon [from sponteneous emission]

Application → $\boxed{\text{laser}}$

1 Conservation of Energy

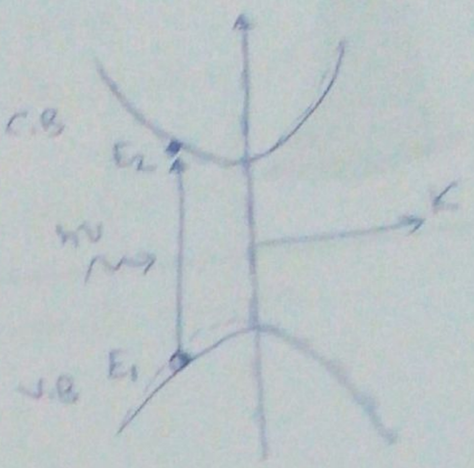
بقاء الطاقة

In Absorption

$$h\nu = E_2 - E_1$$

$$\therefore E_2 = E_1 + h\nu$$

E_2 ↑ Final Energy, E_1 ↑ Intial, $h\nu$ ↑ photon



or emission

$$E_2 - E_1 = h\nu \rightarrow \boxed{E_2 = h\nu + E_1}$$

$h\nu$ ↑ ناتج

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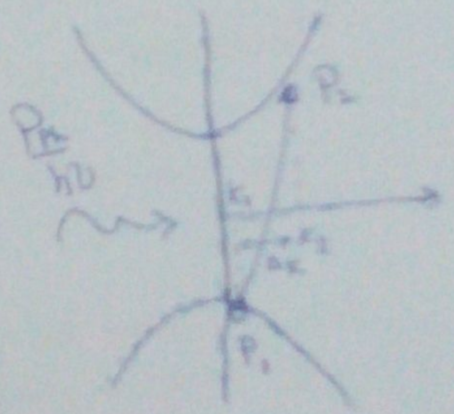
2 Conservation of momentum

momentum → $P_{e\,\text{intial}\,(1)} = \hbar K_1$

$$P_{e\,\text{final}\,(2)} = \hbar K_2$$



$$P_2 = P_1 + P_{ph}$$

$$\hbar K_2 = \hbar K_1 + \hbar K_{ph}$$

$$K_2 = K_1 + K_{ph}$$

K_{ph} ↑ neglected

$$\therefore \boxed{K_2 = K_1} \rightarrow \Delta K = 0 \rightarrow \text{vertical transition}$$

↖ السقوط فوق

لا يسبب تغيّر Momentum

For optical Communication

$\lambda = 0.5 \rightarrow 1.5\ \mu m$

let $\lambda = 1\ \mu m = 10{,}000\ A^\circ$

$$K_{ph} = \frac{2\pi}{10{,}000}$$

For electron $\lambda_e = 10 - 100\ A^\circ$

$$K_1, K_2 = \frac{2\pi}{10}$$

$$K_{ph} \ll K_e$$

page 4

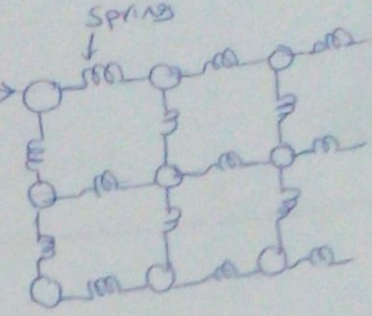
Note

↳ Bonds between atom is elastic bonds (not Static)

ال atoms بتتحرك نتيجة الحرارة مثلاً

atom →

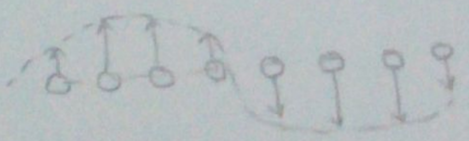
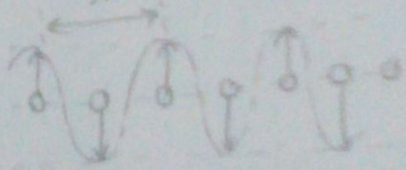
Spring



↳ What is phonon ?

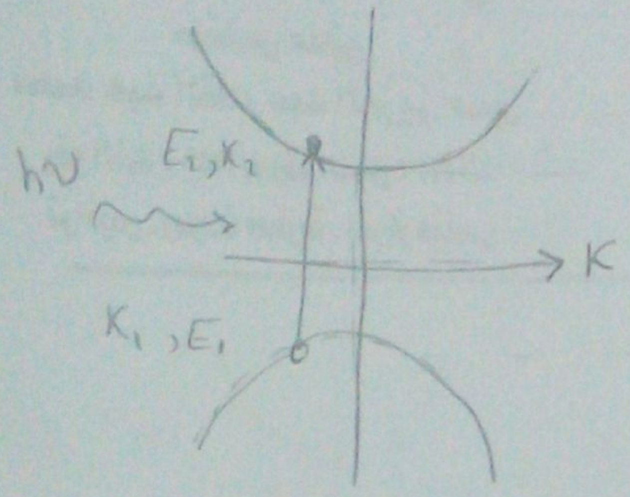
↳ ~~Quant~~ Quanta of lattice Vibrations

↳ Types of Phonon ?

Acoustic phonon	Optical phonon
	$\lambda = 2a$ ← very small  الذرات يحدث لها ازاحة في اتجاهات معاكسة
↳ Group of atoms displaced in Same direction	↳ Atoms displaced in opposite direction
↳ $\lambda \gg$ → ↑↓↓	↳ $\lambda = 2a$ → very small
	↳ $f_{optical} > f_{acoustic}$

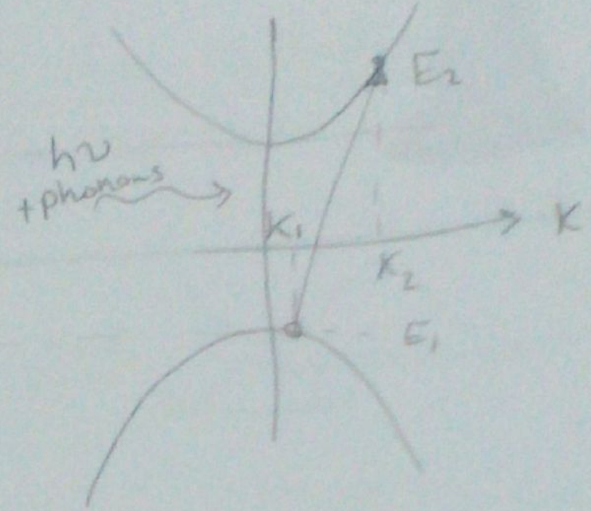
(d) Photon Assisted transition | Phonon Assisted transition

Photon Assisted transition

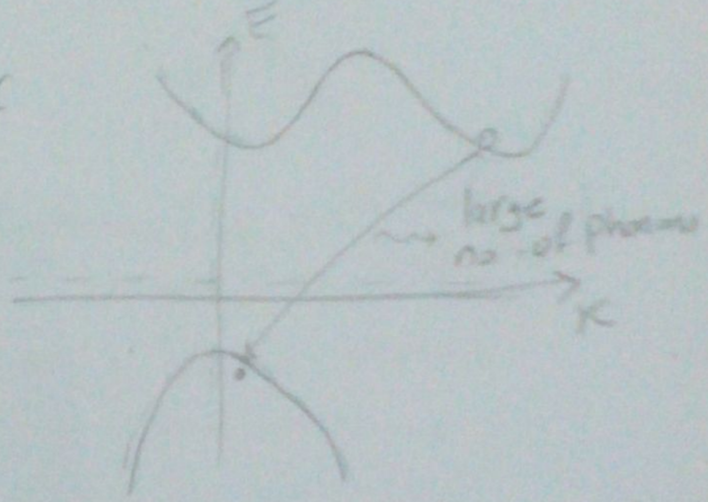


→ Vertical transition (No Change in momentum)

Phonon Assisted transition



or



→ Intial State and final State has different $\underline{K}$

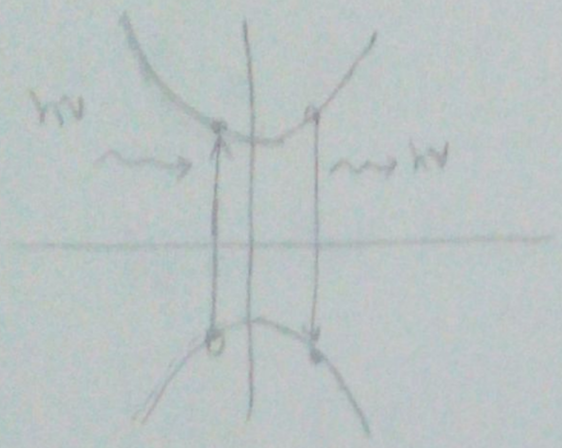
(a)

	Photon	Phonon
Define:	Quanta of light	→ Quanta of Vibrations
Energy	$1\,eV \rightarrow 3\,eV$	→ $10\,meV \rightarrow 70\,meV$
Wavelength	$\lambda = 0.5\,\mu m \rightarrow 1.5\,\mu m$	→ $\lambda = 10\,\mathring{A} \rightarrow 100\,\mathring{A}$
	→ probability of radiation photons is large in direct semiconductor	→ probability of radiation phonons is large in Indirect semiconductor
	→ نفس الرسومات	→ نفس الرسومات اللي فوق [illegible]

C Radiative & Non-radiative :

Radiative

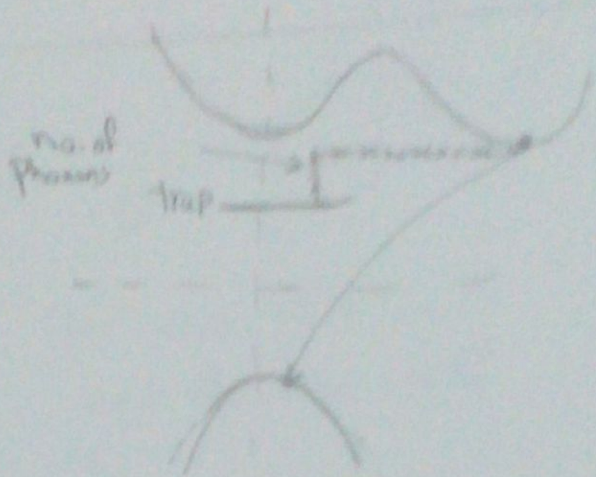
↳ no trap state in Band Gap



↳ Absorption or emission can occure

Non-radiative

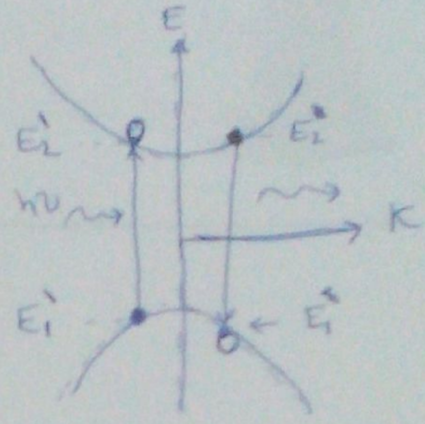
↳ Trap state in Band Gap



↳ recombination with hole can occur in trap state by lossing phonons

↳ Probability of Emission and absorption

↳ In emission, you need electron State in (E₂) and make transition to (E₁) (hole)



$$\therefore \boxed{P_e = f(E_2)\,[1 - f(E_1)]} \rightarrow (1)$$

~~Pa≠~~ In absorption, you need hole in E_2' and electron in E_1'

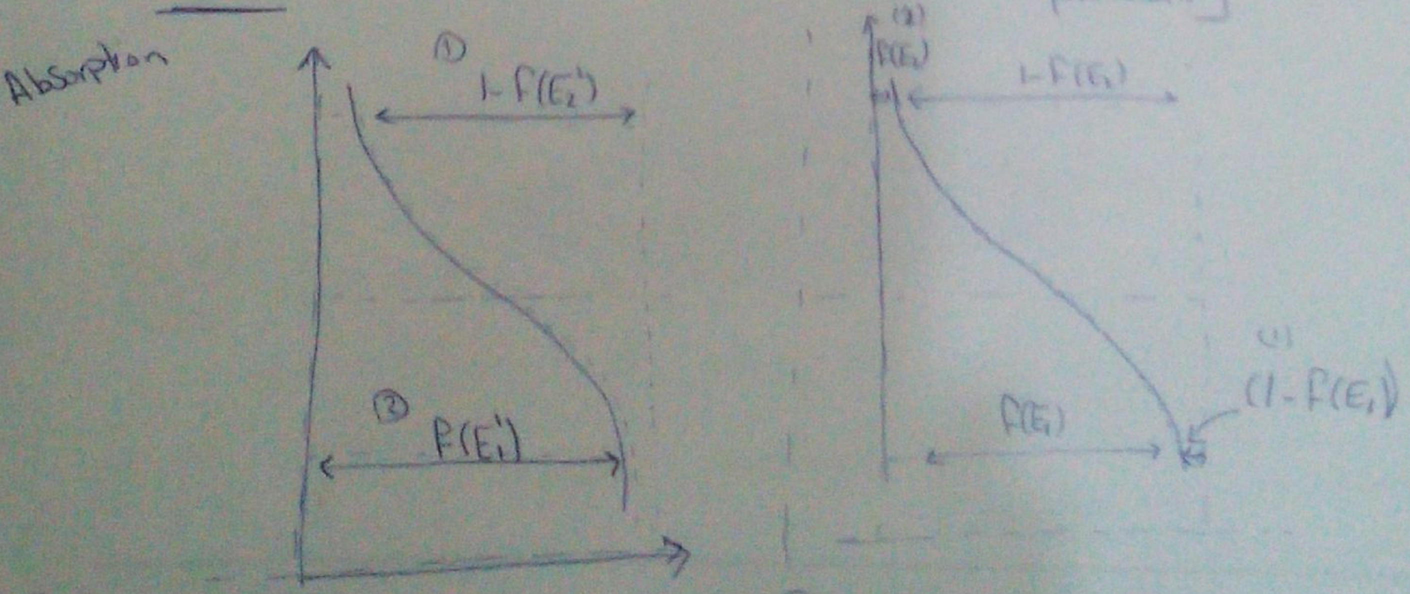
$$\boxed{P_a = f(E_1')\,[1 - f(E_2')]} \rightarrow (2)$$

الهدف من حساب الاحتمال الـ emission لـ Absorption ~~radiation~~

↲ $P_e > P_a$ ← احتمال حدوث الـ emission أكبر ← اقدر استخدمه كـ Source

↔ $P_a > P_e$ ← " " الـ absorption أكبر ← اقدر استخدمه كـ detector

Case (1) Thermal Equlibrium (one Fermi Function discribe probability of electron)



$P_A = (1) * (2) \rightarrow$ large

$P_e = (1)(2) \rightarrow$ Small

$$P_e < P_a$$

Double Hetero structure :

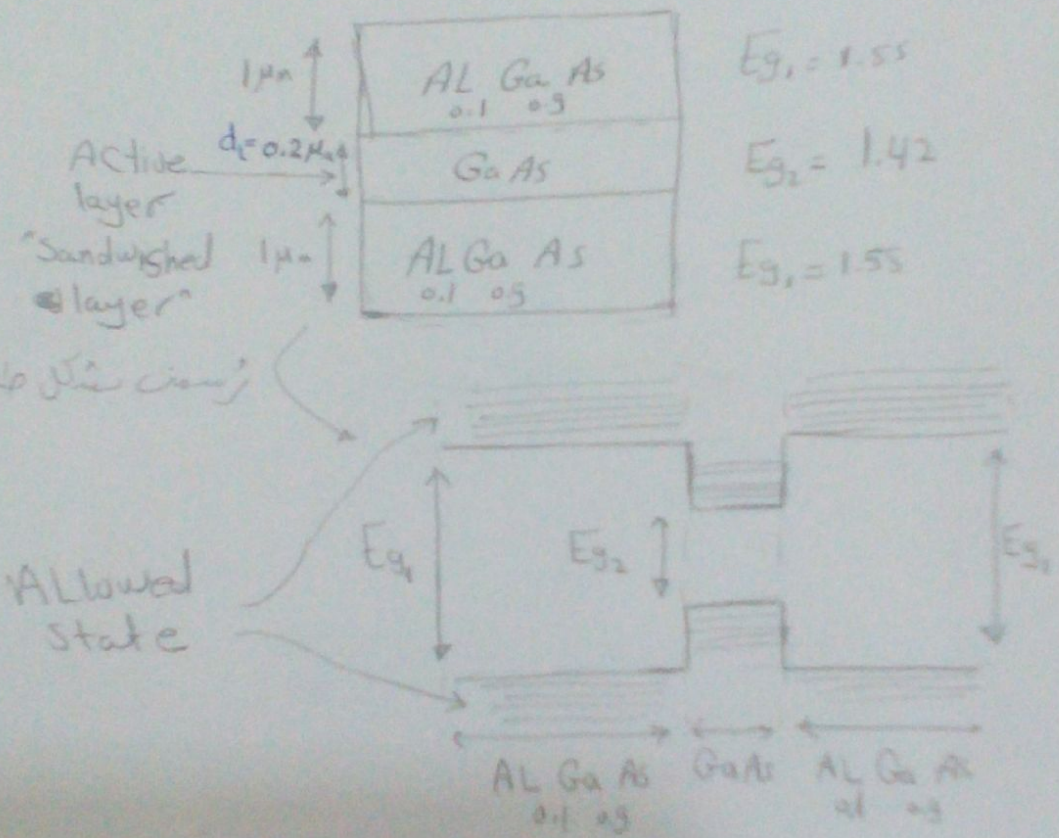
define as : two semi Conductor materials grown into a Sandwish Layer.

outer layer → material has Eg_1

Sandwished layer → Eg_2

& $\boxed{Eg_2 < Eg_1}$

Ex



لـ طول الـ layer بالـ $\boxed{\mu m}$ ← إذا هي Bulk material

لـ إذا يوجد عدد لانهائي من Allowed state

في الـ V.B & C.B

if $\boxed{d_L < \lambda}$ ← debroglie wavelength → $\boxed{\text{Quantum well structure}}$

(الاسم الذي يطلق على الـ Structure

في الـ $d_L < \lambda$